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Development of canine rehabilitation and aquatic therapy

by

Gregory Scott Marsolais

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Major: Veterinary Clinical Sciences (Veterinary Surgery)

Program of Study Committee:
Christopher Brown, Co-major Professor
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Iowa State University

Ames, Iowa

2002

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**Graduate College
Iowa State University**

**This is to certify that the master's thesis of
Gregory Scott Marsolais
has met the thesis requirements of Iowa State University**

Signatures have been redacted for privacy

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ABSTRACT

Information from research with animal models of immobilization and early motion following joint surgery drove human orthopedic surgeons to require physical therapy in their patients. This provided the basis for the physical therapy profession to be formed several decades ago. The same benefits of motion following joint surgery have not yet been explored in veterinary patients, as the first juvenile steps toward postoperative treatment have only been undertaken in the past few years. Few peer-reviewed manuscripts on rehabilitation in animals exist, and recommendations for the design and implementation of rehabilitation programs are nonexistent. This manuscript should serve as one of the first examples of how to establish a rehabilitation program for the canine. This is not an endpoint but rather the beginning. This serves to document the protocols and design of the Iowa State University, Veterinary Teaching Hospital, Canine Rehabilitation Center. This manuscript includes the design and implementation of this program, including but not limited to safety issues, water quality issues, patient care issues, and protocol recommendations. It also includes two of the first scientific reports submitted to peer-reviewed veterinary literature. The first, an evaluation of limb function comparing rehabilitation and traditional exercise-restriction after surgery for ruptured cranial cruciate ligaments, was accepted for publication by the Journal of the American Veterinary Medical Association. The other, a kinematic comparison of terrestrial and aquatic rehabilitation, has been submitted for publication. These scientific reports and this manuscript promote the use of aquatic rehabilitation for canine patients following a variety of orthopedic surgeries.

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Chapter 1. Canine Rehabilitation Facilities and Exercise Protocols

Introduction

Rehabilitation facilities vary with the type of rehabilitation performed. Various modalities exist, including: muscle massage, passive range of motion, treadmill exercise, aquatic exercise, acupuncture, ultrasound, and electrophysiological stimulation.¹

Combinations of therapies may provide the best opportunity for complete care of individual patients. For the Canine Rehabilitation Center (CRC) at the Iowa State University, Veterinary Teaching Hospital (ISU VTH), several treatment modalities have been combined, including passive range of motion (ROM), massage therapy, treadmill exercise, cavaletti exercise, and swimming. Each modality boasts advantages and disadvantages. For example, passive range of motion and massage can be implemented first, almost immediately after surgery if desired. The importance of early range of motion for the long term health of tissues and the detrimental effects of prolonged immobilization will be discussed in chapter 2, however it needs to be mentioned that passive ROM and massage are most valuable in the early postoperative period. During the middle postoperative period (3-8 weeks), treatments need to include strategies to promote early weight bearing and active range of motion. These treatments include treadmill or conventional walking for weight bearing and swimming for range of motion. Massage and passive ROM remain important as a warm up to these activities. Finally, in the late postoperative period (8-16 weeks), activities which maximize range of motion and weight bearing should be implemented. These include treadmill running, agility exercises, swimming with increased duration and against a current, and resumption of a normal activity level.

Goals of Rehabilitation

The word rehabilitation literally means to normalize,² yet rehabilitation following surgical stabilization of orthopedic diseases takes on a different meaning. The goal remains to return to normal; however diseases like cranial cruciate ligament rupture (CCLR), disrupt normal anatomy. New goals must be established, as “normalizing” a joint with changed anatomy is impossible. These should focus on maintaining the health of the existing tissues, preserving ROM, strengthening muscles and ligaments, decreasing swelling, fibrosis and postoperative pain, and maximizing dynamic stability. Like rehabilitation protocols, goals are patient specific. Long term plans for the overweight sedentary dog are more likely to include pain management, weight loss, and improved quality of life rather than return to agility, rescue work, and hunting. Likewise, athletic breed dogs are likely not to require much weight loss and instead may focus upon returning to pain free function, be it field trials, hunting, or human companionship during exercise.

The key to success of a rehabilitation program is establishing reasonable goals. Client expectations figure heavily into this and therefore good communication is tantamount. Clients need to be informed of your expectations for their pet, and they must be prevented from having unreasonable goals themselves.

Facilities and Equipment

The facilities and equipment will vary with the type of rehabilitation that will be performed and the species represented. For the ISU VTH CRC, aquatic therapy was selected as the primary modality, the benefits of which will be discussed in chapter 2. In order to be successful with this modality of therapy, a large stand-alone pool unit was selected. It was

determined that the pool needed to be of sufficient length, width, and depth for giant breed dogs, provide a current to challenge reluctant and fit animals, and be able to allow staff to provide a safe environment. With that in mind, the Aquaswim 'N' Spa^a was selected and purchased, which stands 4'0" high, 14'0" long, 7'6" wide, and came equipped with a heating unit,^b and a pump, filtration and swim jet unit.^c A room size of 48ft x 30ft x 14ft was required to accommodate the unit and it had exterior access to allow easy daily maintenance and quarterly draining. The pool was stabilized and balanced on the floor as per manufacturer's recommendations. An outer covering was built from 1" plywood and covered with outdoor carpeting to protect access to the underneath side of the pool. As the unit is free standing above the floor, an outer ramp and loading platform were also built. The ramp was constructed from several sheets of 1" thick plywood cut to a width of 2'. The ramp rose to a total height of 4', flush with the loading platform over a 16' distance. A steeper grade may have caused additional difficulty in getting patients to the loading ramp and added unneeded stresses to unstable joints. The ramp was reinforced with 2" x 4" redwood lumber, mounted to the outer plywood covering of the pool along the long axis and covered with outdoor carpeting. The loading platform was constructed level and flush with the top of the pool along the short axis near the stairs into the pool. It was built from 1" thick plywood cut to 2' by 4', reinforced with redwood 2" by 4" lumber, and covered with outdoor carpeting. Both the ramp and the loading platform were secured together and to the pool. A 2' high rail was attached to the outer side of the entire ramp and loading platform.

^a ASJ-SP-14' Swim spa, Rio Plastics, Brownsville, Texas 78523

^b 1240627 Spa Heater, Coates Heater Company, Kent, Washington, 98032

^c APAC-1619-DT-D, Rio Plastics, Brownsville, Texas 78523

Staff

Qualified personnel are arguably the most important component of a rehabilitation facility. The care and rehabilitation of patients cannot be effectively performed without dedicated, trained staff. For the ISU VTH CRC, the minimum requirements set for the staff was to have a valid Iowa license as a Registered Veterinary Technician. Additionally, staff must attend continuing education as is required by Iowa. More important than licensure was the ability to demonstrate excellent nursing skills as well as the ability to adapt treatment regimes to individual patients. Most of the patients that enter the CRC are in the early post-operative period and subsequently need more care and daily assessment than the typical dog. Staff must also maintain the ability to assess housing and care needs. There are significant differences in athletic levels between most dogs, and trained staff can provide safe, meaningful rehabilitation, for each individual participant.

Housing

Boarding of patients requires safe comfortable housing. It also requires the staff to assume responsibility for feeding, regular walks for urination and defecation, and play time. Space to house these dogs and time to provide all the necessary treatments are a must. While large spacious runs may be ideal, due to space limitations, dogs were housed in stainless steel cages^d 48" wide, 36" long and 36" high. Cages were suspended 4" above the floor and have a slatted floor to allow urine, feces, and water to pass. Rubber mats and blankets were placed in the bottom of the cage to allow the dogs a comfortable resting area. Dogs were walked at a minimum of four times daily, fed twice daily as per their owners' instructions, and

exercised twice daily. All of the housing, feeding, walking, and treatments are overseen and coordinated by the same registered veterinary technician.

After boarding all bedding materials are removed and laundered, each cage is sprayed with Quat disinfectant,^e allowed to soak for ten minutes, rinsed, and allowed to dry. Cages are periodically autoclaved in the Laboratory Animal Research facility.

Exercise Protocol

Exercise protocols must be dynamic. Protocols must be tailored to the individual patient, or accomplishment of the rehabilitation goals is unlikely. For example, the activity level of an overweight sedentary dog is obviously different than a fit athletic dog. The injury and surgical management may be identical; however the postoperative rehabilitation must be tailored to fit the dog. The fit animal will reap the benefits of the additional exercise that the sedentary animal could not tolerate.

The protocol suggested here is merely a starting point. It has evolved significantly since the beginning of the program at the ISU VTH CRC. In our experience, interval training maximizes the duration of exercise and minimizes the fatigue experienced by the patient. A warm-up period precedes all active exercise and includes passive ROM and massage therapy. The warm-up period is important in preventing injuries by loosening stiff joints, promoting blood flow to tissues, and mentally preparing the patient for activity. The passive ROM and massage therapy are combined as one activity which lasts between ten and fifteen minutes. ROM is done with the patient's natural flexion and extension, not against them and all

^d Wahmann Mfg Co, Baltimore, MD.

^e Quat Disinfectant Cleaner, 3M/Home and Commercial Care Division, St. Paul, MN.

abnormal rotation and bending must be avoided. It is important that the motion is slow, steady, painless, and with the natural movement of the joint. The joint should alternate between pain free flexion and extension to such a point that resistance is met, and be held for five seconds. Massage of muscles should be done at the same time. Upon completion of passive ROM and massage, the patient should be walked between ten and fifteen minutes. During favorable weather conditions, walks may be done outside; however the treadmill is a valuable tool when weather conditions do not permit such activities. As rehabilitation progresses, the patient may not be challenged by mere walking. The treadmill is excellent for challenging the patient to walk up hills and at faster rates. Increasing the workload of these patients must be done with caution. Challenging patients too early can inhibit their progress by causing re-injury. Additionally, habituation should be performed on the treadmill and in the pool before beginning either exercise for the first time. This ensures that patients are comfortable with their surroundings prior to strenuous work.

Swimming is the essence of aquatic rehabilitation for animals. Dogs are not currently trained to do single joint flexion or extension, or other exercises that humans routinely perform in the aquatic medium. It should also be noted that the walking on a treadmill while partially immersed in water is not an aquatic exercise. Although utilizing the aquatic principle of buoyancy, this is a terrestrial exercise and ground reaction forces are transmitted up the limb. Aquatic principles are discussed in chapter 2. Interval training has allowed patients to swim longer and fatigue less than long duration swims without rest. This is safer for the patient and provides greater functional time of exercise. Initially, the patient needs to

be habituated to the pool and the life preserver.^f Some are willing to swim immediately, while others need coaxing. For the apprehensive, a period of sitting in the shallow end may relieve fears. In addition to safety, ropes fastened to the life preserver allow the patient's location in the pool to be controlled. Once the swimming session begins, the dog should be allowed to swim to such a point that their feet are not touching the bottom of the pool. Most dogs naturally swim at this point, however some may need encouragement. We have found that the use of tennis balls, toys, and verbal coaxing is useful in many cases. Only the most stubborn cases warrant using a water current from the swim-jet to encourage activity. Initially exercise occurs for one minute unless the patient labors sufficiently, becomes cyanotic, or struggles uncontrollably. Most swim for the minute without difficulty. Upon completing the minute swim, the patient is returned to the shallow end of the pool and allowed to rest for one minute. Despite the short duration of activity, most patients are tired. The interval is repeated until a total of five minutes of swimming have been performed. The first swim will reveal how much exercise the dog will endure and what graded increases in length of intervals and number of intervals may be planned for subsequent sessions.

Each session includes passive ROM, massage, walking, and swimming. Sessions should be repeated twice daily. Graded increases in demands on these patients should be undertaken with caution. Most dogs are tired at the end of each session, especially after the swimming. The object is to challenge, yet excessive exercise early in the program can be counterproductive by causing pain and inflammation in unstable structures. If indications of these are discovered, sessions should be skipped and the patient be monitored. Exercise

^f S.E.R.F. Leisure Products Inc., Mississauga, Ontario, Canada

should be slowly initiated only after adequate rest. Some cases may warrant reevaluation by a veterinarian.

Following all swimming sessions, dogs should be rinsed and dried with a towel. They should then be placed in a drying cage. The ISU VTH CRC uses a Challengeair 550,^g and Bur-Otic^h drying solution for excess water in the ears. Finally, these post-rehabilitation patients need to have access to ample volumes of clean drinking water.

Inpatient or Outpatient

The choice to allow patients to remain as an inpatient (boarding for the week) or conduct rehabilitation as an outpatient varies with owner's wishes and clinician decision. In most cases, rehabilitation is performed on an inpatient basis, which serves to minimize complications associated with time constraints, feeding before exercise, and scheduling of patients. On several occasions, however, local patients have been allowed to enroll as outpatients.

In humans, there were no differences found in return to function between inpatient and outpatient rehabilitation.³ Similar experiments in animals have yet to be completed. Each protocol, inpatient or outpatient, may have specific advantages and disadvantages. Inpatient rehabilitation avoids owners skipping sessions, tardiness at drop-off and pick-up appointments, owners feeding their pet before the morning exercise session, and allows the schedule to maximize the number of patients rehabilitated for the entire week. However, due to cost issues, separation issues, and often, long transport distances between home and ISU,

^g Double K Industries, California

^h Virbac Inc, FT. Worth, Texas

most owners elect to rehabilitate every other week. Outpatients may receive more consistent rehabilitation by participating two or three days per week. The effects of alternating week versus alternating day rehabilitation have yet to be tested.

Safety Issues

Safety is the key to the longevity of any program. This directly relates to patient and staff safety and quality of work environment. In the CRC, several issues have arisen. The first problem encountered was lifting difficulties. Often in the first exposure to swimming, patients are reluctant to walk up the ramp to the pool and climb the steps into the water. This requires the technician to assist by lifting in awkward places (i.e., when the patient is on the ramp). To avoid back injuries a second technician must be available for lifting, especially on the days when new patients begin rehabilitation. Another problem that arose came from aggressive dogs. To combat this, these patients are not admitted to the program.

Injury to non-staff persons may also be an issue. One potential hazard which has been identified in the CRC was unauthorized access to the pool. The potential for drowning or injuries occurring during the unauthorized use of the pool was significant. In an effort to minimize the risk, pool coversⁱ that attached to safety locks were purchased and put into effect. The standard operating procedure for pool use states that when the pool is unattended it is to remain covered and locked.

Water Quality

The National Swimming Pool Foundation of America has published guidelines for the maintenance of therapeutic pools.⁴ There are no published guidelines for canine rehabilitation pools at this time, and therefore human standards for pool care were adopted. They include, but are not limited to, maintaining the water at a temperature between 90° to 92°, total alkalinity at 80 to 120 PPM, total bromine concentration at 3 to 5 PPM, and pH at 7.2 to 7.6. It is important to note that microbiology testing was performed to detect the adequacy of bromine levels in the killing of microbes in the water. This testing revealed that water sampled immediately after dogs were in the water yielded high numbers of skin flora and *Pseudomonas aeruginosa*.^j Following four hours of constant filtration with recommended bromine concentrations, the water was found to be free from microbes. Testing of the water is necessary to ensure that pathogenic bacteria do not come to inhabit the pool or any of its associated structures. Additionally, it is important to note that should fecal contamination of the pool occur, the pool must be drained, sprayed with a disinfectant, rinsed, and allowed to sit to dry, before the pool is refilled and rehabilitation is resumed. This process requires a full 24 hours to complete, and patient selection is a key component to prevent fecal contamination and subsequent pool maintenance. This is an issue with some neurologically compromised patients and we have recommended swimming animals that are fecally and urinary incontinent in smaller pools that can be changed between usage.

ⁱ Panorama Cabana Inc., Kansas City, MO

^jDepartment of Clinical Microbiology, Iowa State University, Ames, Iowa.

Recording Success

Documentation of the success of a program can be done in a variety of ways, and some are objective while others are subjective. Objective modalities of gait assessment include force platform gait analysis (discussed in Chapter 2), kinematics (discussed in chapter 3), and total body weight. Body condition score, passive range of motion, owner satisfaction, and visual observations (lameness assessment) are all subjective, yet they remain a valuable measurement of quality of rehabilitation program.

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Chapter 2. Effects of Postoperative Rehabilitation on Limb Function after Cranial Cruciate Ligament Repair in Dogs.

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Introduction

Rupture of the cranial cruciate ligament (RCCL) is a common cause of lameness and is also the most commonly diagnosed stifle injury in dogs.¹ Nonsurgical management of dogs with a body weight greater than 15.9 kg (35 lb) provides a satisfactory outcome (lameness less than 1 day/week) in < 20% of cases.^{2,3} Using variables such as orthopedic examination, client questionnaire, and force plate gait analysis, reports have documented success following surgical management of RCCL in dogs in 51 to 100% of cases.⁴⁻⁹

Although much attention has been given to the role of various surgical techniques for repair of RCCL, peer-reviewed literature addressing the role of postoperative management is scarce. Anecdotal reports suggest postoperative management should include application of a Robert Jones bandage for up to 14 days and activity restricted to a leash for up to 12 weeks.^{10,11} Most of this management is seemingly geared toward increasing the strength of periarticular fibrous tissue and mechanically protecting the repair technique.

It has been demonstrated that prolonged immobilization after joint surgery is closely associated with degenerative alterations in connective tissue, cartilage, ligaments, muscles, and bone-ligament complexes, while allowing for hypertrophy of periarticular fibrous

tissue.¹²⁻¹⁸ Studies in humans have revealed that restricted knee motion after **anterior cruciate ligament (ACL)** reconstruction in people contributes to joint pain, muscle atrophy, decreased joint mobility, increased arthrofibrosis, soft tissue weakness, and functional impairment.¹⁹⁻²² In dogs, loss of joint mobility and joint instability disrupt normal joint kinematics and can lead to osteoarthritis.^{23,24} Similarly, in humans, loss of mobility causes pain and effusion after prolonged weight bearing, crepitus during extension, altered gait, decreased knee function, and reduces the likelihood of return to complete function.^{13,17,19,20}

Alternatively, early motion and aggressive postoperative rehabilitation after ACL surgery in humans has been reported to improve prognosis.²⁵⁻²⁷ Early physical rehabilitation results in earlier and more complete return to function (often by 4 to 6 months after surgery) and reduces the chances of re-injuring the joint, and does not increase intra-articular graft failure rates.²⁸⁻³¹ In athletes recovering from ACL surgery, it has been reported that physical rehabilitation reduces pain, joint effusion, capsular contraction, and periarticular fibrosis while increasing range of motion, muscle mass, and limb strength.³²⁻³⁵ Finally, it has been suggested that early postoperative physical rehabilitation reduces the development of arthrofibrosis and osteoarthritis.^{25,36}

In animals, rehabilitation has been suggested to decrease muscle spasm, promote tissue healing and repair, increase range of motion, decrease edema, and increase muscle strength and endurance.³⁷⁻⁴¹ Improved range of motion, cartilage nutrition, and orientation and strength of collagen fibers in the CCL of animals are additional beneficial effects of early motion following joint surgery.⁴²⁻⁴⁵ It has been suggested that low impact exercises, including swimming and walking, avoid worsening of osteoarthritis while maintaining muscle strength, joint mobility, and function.³⁶ Finally, it has been reported that rehabilitation

after joint surgery decreases adhesions, is valuable for maintenance of muscle mass, bone, cartilage, and ligaments, and provides the stress needed for reorganization of transplanted tissues.^{44,46-47}

The purpose of the study reported here was to determine the effects of early postoperative rehabilitation on limb function in dogs after surgery for repair of RCCL.

Materials and Methods

Dogs— All adult dogs examined at the **Iowa State University Veterinary Teaching Hospital (ISU VTH)** between June 1999 and December 2000 were considered for inclusion in the study. Selection criteria included a body weight between 20 and 40 kg (44 and 88 lb), unilateral RCCL, complete tear of the **cranial cruciate ligament (CCL)**, presence of medial meniscal injury (intra-articular pathologic aberrations confirmed at surgery), and absence of other neurologic and orthopedic diseases. Additionally, all dogs were withheld from nonsteroidal anti-inflammatory medications for 7 days prior to enrollment in the study and all owners signed an informed client consent form. Postoperative rehabilitation was offered to all owners at no additional cost. Dogs were then assigned to 1 of 2 treatment groups, postoperative rehabilitation or exercise restriction. In effect, dogs were not randomly assigned to treatment groups; they were assigned based solely on their owner's decision to have the dog participate in postoperative rehabilitation. In addition, the investigators were not blinded to the treatment groups.

Data collection—Data were generated from the patient's history (duration of lameness), signalment (body weight, breed, age, sex) and physical examination findings (body condition score). Force platform gait analysis was performed before surgery and 6 months after

surgery in all dogs using a floor-mounted force platform.^k The acquired data were sent through an amplifier^l to an IBM compatible computer.^m The first 5 valid trials for each set of limbs were used for data analyses. A valid trial consisted of a forelimb foot strike, with the complete foot striking the force platform and no other foot being on the platform at the same time, followed by an ipsilateral hind limb foot strike in the same fashion. All valid trials had a patient torso velocity of 1.1 m/s to 1.3 m/s and acceleration of $\pm 0.5 \text{ m/s}^2$. Velocity and acceleration were measured using 3 photoelectric cells, placed 1.0 m apart coupled with a triggered timer system. The middle cell was centered at the middle of the force platform. Visual observation was used to ensure that the animal was not distracted during the trial and that each footfall was near the center of the force platform. **Peak vertical force (PVF)** and **vertical impulse (VI)** were determined by use of softwareⁿ specific for force platform gait analysis in dogs.

The selected velocity of 1.1 to 1.3 m/s was a walking pace in all dogs. This velocity was selected because many lame dogs that would use the affected limb at a walk would carry the limb at a trot, thereby adding to trial variation. Given the degree of lameness in the dogs in this clinical study, gait analysis at a walk was deemed most appropriate. Data collection was also attempted at 1 and 2 months after surgery. Lack of client compliance (not returning the dogs for the 1- and 2-month examinations) for dogs in the exercise-restricted group forced us to eliminate these examination times.

Surgical treatment—Treatment included surgical debridement of the RCCL, complete medial meniscectomy, and lateral retinacular imbrication stabilization using 2 sutures from

^k Model OR6 5 Biomechanical Platform, Advanced Mechanical Technologies, Inc, Watertown MA

^l Model SGA/MCA Strain Gauge Amplifier, Advanced Mechanical Technologies, Inc, Watertown, MA

^m Gateway P5-166, Pentium II 166 MHz

the lateral fabella to the tibial tuberosity. The same surgeon (MGC) performed all surgeries. Postoperative care included administration of an analgesia (0.5 mg/kg [0.23 mg/lb] morphine, IV, q 6 h for 24 hours) and a 2- to 3-day stay in the hospital with short leash walks twice daily. No additional analgesic or anti-inflammatory medications were offered on discharge.

Rehabilitation group—All dogs were discharged from the hospital 2 to 3 days after surgery without a bandage. Owners were instructed to rest the dog at home with activity limited to primarily short (0.3 miles) walks on a leash (for urination and defecation only), twice daily, until suture removal. At 10 to 12 days after surgery, dogs were returned to the ISU VTH for reexamination and suture removal. These reexamination appointments were scheduled on Monday mornings so that the dogs could begin rehabilitation in the beginning of the third week after surgery. Rehabilitation was performed twice each day during weeks 3, 5, and 7 after surgery. During weeks 4, 6, and 8 through 16 after surgery, owners were instructed to take the dogs on leash walks, twice each day, up to but not greater than 1 mile. Owners were instructed to walk at a pace that encouraged use of their dogs' affected limb and discontinue the walk if the dog would not voluntarily use the limb. At the conclusion of week 16, owners were instructed to allow their dogs to have unlimited exercise.

All rehabilitation sessions took place at the VTH canine rehabilitation facility. Sessions began with 10 minutes of limb massage and placing the limb through a passive range of motion, followed by 10 minutes of walking and 10 to 15 minutes of swimming. Prior to swimming, each dog was fitted with a personal flotation device^o and walked into the

ⁿ Acquire, Sharon Software Inc, Dewitt, MI

^o S.E.R.F. Leisure Products Inc., Mississauga, Ontario, Canada

pool. Swimming therapy began with alternating intervals of a 1-minute swim followed by 1-minute of rest. This regimen was repeated twice daily (am and pm) so that each dog received at least 10 minutes of swimming daily. Depending on each dog's physical condition, the duration of each swimming interval could be increased up to 2 minutes, thus doubling the total swimming time. Nearly all dogs swam vigorously (limbs continuously moving) from the time they were suspended (no limbs touching the floor or stairs); however, a few required the use of a ball to encourage their activity. Swimming was performed in a pool^p that is 7'6" feet wide, 14 feet long, and 4 feet deep. Temperature, total alkalinity, total bromine concentration, and pH were maintained in accordance to standards set by the National Swimming Pool Foundation of America.⁴⁸ The water temperature was maintained between 90° to 92°, total alkalinity at 80 to 120 PPM, total bromine concentration at 3 to 5 PPM, and pH at 7.2 to 7.6. Dogs were housed in stainless steel cages in the rehabilitation facility for the duration of the weeks they were undergoing treatment and were fed their normal diets as instructed by their owners. Therapeutic walks were performed outdoors or on a treadmill.^q Each dog completed 30 rehabilitation sessions during weeks 3 through 7 after surgery.

Exercise-restricted group—All dogs were discharged 1 to 3 days after surgery without a bandage. Owners with dogs assigned to the treatment group received oral and written discharge instructions that included resting their dogs at home with activity limited to twice daily, short (0.3 miles) leash walks (for urination and defecation only) until 8 weeks after surgery. Suture removal was performed 10 to 14 days after surgery at the VTH or at the owner's referring veterinarian. During weeks 8 through 16, owners were instructed to take

^p Aquaswimjet-Swimpool 14', Rio Plastics, Port of Brownsville, TX

^q ICON Health and Fitness, Inc., Widestride Duo48, Logan, UT, 84321

the dogs on leash walks, twice each day, up to but not greater than 1 mile. Owners were instructed to walk at a pace that encouraged their dog to voluntarily use the affected limb and discontinue the walk if the dog did not use the limb. At the conclusion of week 16, owners were instructed to allow the dog to have unlimited exercise.

Data analyses—All data are reported as mean \pm SE and are expressed as a **percentage of the dog's body weight (% BW)**. Comparisons of vertical forces were determined between and within groups over time using a repeated-measures 1-way ANOVA. Values of $P < 0.05$ were considered significant.

Results

Twenty-five dogs were included in the postoperative rehabilitation group. Twenty-six dogs were included in the exercise-restricted group. Significant differences were not detected between groups regarding mean duration of injury, body weight, age, or body condition score. Mean body weight for dogs in the postoperative rehabilitation group was 37.66 ± 0.62 kg (82.8 ± 1.36 lb), compared with 37.57 ± 0.63 kg (82.6 ± 1.38 lb) for dogs in the exercise-restricted group. Mean age was 5.15 ± 0.76 years for dogs in the rehabilitation group and 5.33 ± 0.30 years for dogs in the exercise-restricted group. Mean body condition score, on a 1 through 9 rating system (with 1 being gaunt and 9 being obese), for dogs in the rehabilitation group was 6.54 ± 0.19 and for dogs in the exercise-restricted group was 6.50 ± 0.22 . Mean duration of the RCCL injury for dogs in the rehabilitation group was 6.29 ± 0.24 weeks and 5.86 ± 0.45 weeks for dogs in the exercise-restricted group. Additionally, there were no differences in the distribution of sex or breed between groups. Several breeds were represented in both groups; however, Labrador Retrievers represented over half of the

dogs in both groups. Prior to surgery, mean PVF and VI in injured limbs were similar between groups. Six months after surgery, PVF and VI increased significantly in the affected limbs in dogs in both groups (**Fig 3**). However, PVF and VI in dogs in the rehabilitation group were significantly greater than those of dogs in the exercise-restricted group. At this time, dogs in the rehabilitation group had no difference in limb function (as measured by PVF and VI) between the affected and normal hind limbs (**Figure 1 and 2**). Conversely, limb function in the affected limb of dogs in the exercise-restricted group was still significantly less than that of the contralateral normal limb. The PVF in normal limbs did not significantly change over time, although there was a decrease ($P = 0.09$) in the VI in the normal hind limbs in dogs in the rehabilitation group.

Discussion

Results of our study indicate that a postoperative rehabilitation program will most likely result in improved limb function (as measured by gait analysis) in dogs after surgery for a RCCL, compared with dogs that were exercise-restricted. We are not suggesting that the rehabilitation protocol we describe (passive range of motion, walking, and swimming introduced 10 to 14 days after surgery) is necessarily the best protocol, but a safe, reasonable starting point. In fact, we can identify several areas that might improve the program we used.

Postoperative rehabilitation performed incorrectly can be deleterious to the patient's recovery. It has been shown that exercise strengthens and tones muscles, which ultimately aids in the stabilization of joints^{36, 49} as long as the exercises do not repeatedly stress joints. Osteoarthritis, degeneration of articular cartilage and formation of new bone at joint surface margins, are responses to instability and repeated stresses.^{36, 50, 51} Much like the effects of

arthrofibrosis, osteoarthritis leads to pain and discomfort, limited ability to perform, restricted activity, and a decreased quality of life.³⁶ Obesity and repetitive impact stresses of joints are risk factors associated with increased occurrence of osteoarthritis,³⁶ and should be taken into account when designing a patient-specific rehabilitation program. When initiating a rehabilitation program for a patient with disuse muscle atrophy or obesity, activities that parallel the degree of atrophy and the patient's body condition should be considered. Most of the dogs in our study had obvious disuse muscle atrophy (duration of injury almost 6 weeks in dogs in both groups) and were overweight (increased body condition score).

We elected to focus on swimming in our postoperative rehabilitation program to avoid repeated high impact loads on diseased joints, especially in dogs that were overweight. Perhaps the greatest benefit of aquatic rehabilitation originates from the principle of buoyancy, which decreases the effects of gravity.⁵²⁻⁵⁴ On land, joint reactive forces can reach several times body weight. In water, the effects of gravity and axial loading can be substantially diminished⁵³ or be entirely eliminated if the patient floats.⁵⁴ Additional benefits of water include the effects of hydrostatic pressure and specific heat.⁵² It has been suggested that hydrostatic pressure can reduce joint edema and warm pools can promote relaxation of the patient, increase blood flow to the muscles, and decrease pain.^{32,54,55}

Performing a study evaluating limb function in dogs with naturally occurring RCCL is problematic because of the inherent number of variables that must be controlled for. In this study, we controlled for other orthopedic or neurologic diseases, body weight, the presence of meniscal injury, surgical technique, surgeon, and postoperative management. Severity of preoperative osteoarthritis is an example of an important variable that we did not control for or measure during this study. We limited data collection to gait analysis because

investigators were not blinded to the dogs' treatment group and because of the subjective nature of other variables such as an owner questionnaire, pain-free range of motion, amount of cranial drawer, and thigh circumference. Dogs in this trial were not randomized. Although each owner was offered rehabilitation at no additional cost, many were reluctant based on the distance of travel required from their homes. Monetary compensation may have alleviated these problems. A few owners were unwilling as this was considered new and aggressive therapy. Client compliance issues also arose as we had initially scheduled the collection of force platform data at 1 and 2 months after surgery. Because all dogs in the rehabilitation group were present at the hospital, their data were readily collected. Owners of dogs in the exercise-restricted group, however, were reluctant to return except for the 6-month checkup. Although these data would have been beneficial, we do not feel that their absence detracts from our findings. The effectiveness of postoperative rehabilitation, although initiated in the postoperative period, must have a long-term beneficial effect for it to be more uniformly considered as part of regular treatment regimen for a RCCL in dogs. Although owners were sent home with oral and written discharge instructions, we acknowledge that we could not control treatment once the patient was discharged. A log of the dogs' activities at home (distance walked daily, number of times the dog limped or carried the limb, medications given) may have been helpful.

In this study we performed gait analysis with the dogs at a walk. It is possible that gait analysis at a trot, a more rigorous gait, would have provided different results. As stated, we performed gait analysis at a walk because many dogs that would use the limb at a walk would be non-weight-bearing at a trot. This was especially true in dogs prior to surgery, an important data point.

Budsberg et. al.⁹ previously reported on nine dogs with unilateral RCCL that received similar surgical treatment and had a postoperative protocol included bandaging for two weeks and exercise restriction for an additional six weeks. They found that at reexamination (7-10 months after surgery) PVF of the operated limb had returned to normal. Although our findings suggest that dogs with this type of postoperative treatment on average do not return to normal function it is difficult to directly compare findings. First, we are uncertain of velocity of gait analysis in the previous report. Second, all dogs in this study had a medial meniscal injury and complete meniscectomy; this was not uniform in the previous report. Third, our reexamination time period was earlier (six months) and relatively narrow. It is possible that dogs in the exercise-restricted group would have continued to improve, perhaps all the way to normal. Finally, of the twenty-six dogs in the exercise restriction group in this study certainly some had normal PVF at six months; thus although it is possible for dogs reach normal limb function (as measured by gait analysis at a walking pace) it just doesn't occur on average in that reevaluation time frame.

We believe the effect of postoperative rehabilitation observed in this study was clinically significant. If measured differences were limited to a few percent, then additional rehabilitation might not be warranted. This, however, was not what we found. Dogs in the rehabilitation group had a PVF that was 18.5% greater than dogs in the exercise-restricted group 6 months after surgery. Similarly, VI was 13.9% greater in the rehabilitation group. The most encouraging finding, however, was that dogs in the rehabilitation treatment group had a mean PFV and VI that were statistically identical to that of the contralateral normal limb.

Dynamic stability (strength, endurance, appropriate recruitment of muscle fibers, and timing) is essential for normal joint function. Rehabilitation programs should strive to increase dynamic stability, aim for early return to function, and increase quality of life of the patient. These allow for the return to normal activities without episodes of instability. Additional goals should include progressive weight loss in overweight patients and maintenance of joint mobility while trying to minimize the risk of re-injury. In this study, we demonstrated that dogs that received postoperative rehabilitation following surgery for a RCCL had improved limb function 6 months after surgery. Although we elected to focus our rehabilitation program on swimming, we are not suggesting that the regimen that we used is the only one that could be successful. We also elected to provide all dogs with the same rehabilitation program which we are not suggesting be the only regime; each dog should receive a program tailored specifically for their needs. However, we are suggesting that the typical dog that has surgery for RCCL benefits from postoperative rehabilitation and that it should be considered as part of the standard care provided to these patients.

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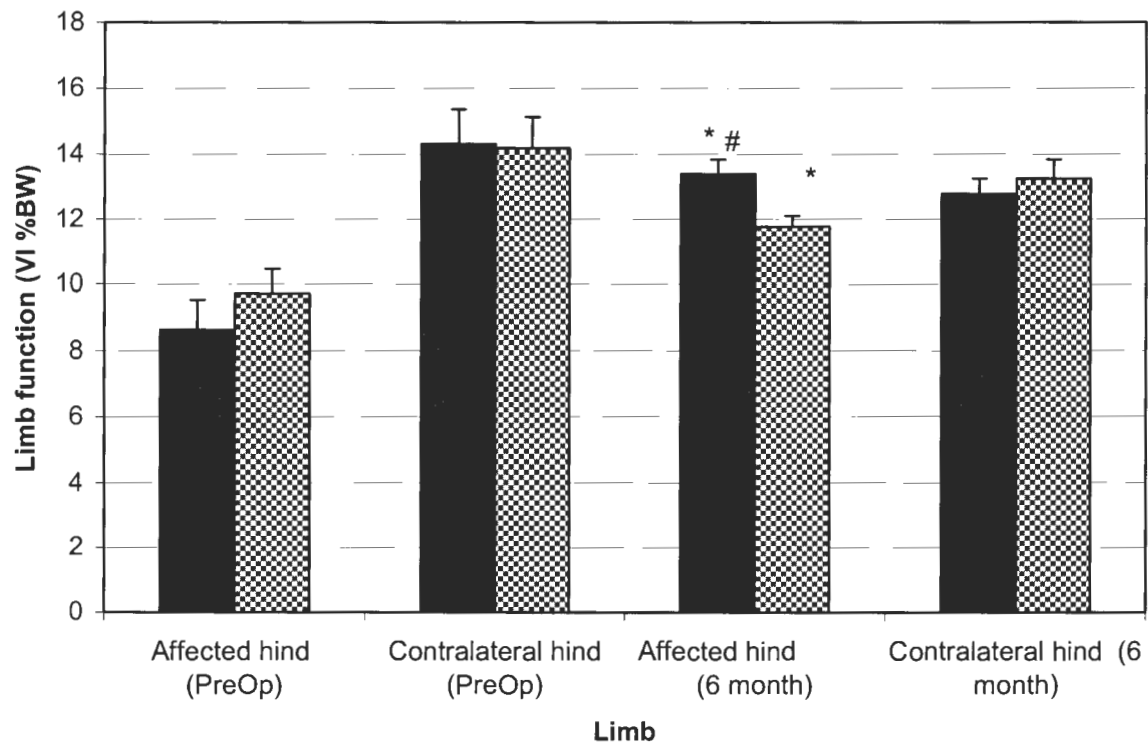


Figure 1. Comparison of vertical impulse (VI) for dogs in the rehabilitation group (■) and dogs in the exercise-restricted group (▨) preoperatively and at 6 months after surgery. * Significant ($P<0.05$) difference between time 0 and 6. # Significant ($P<0.05$) difference between groups.

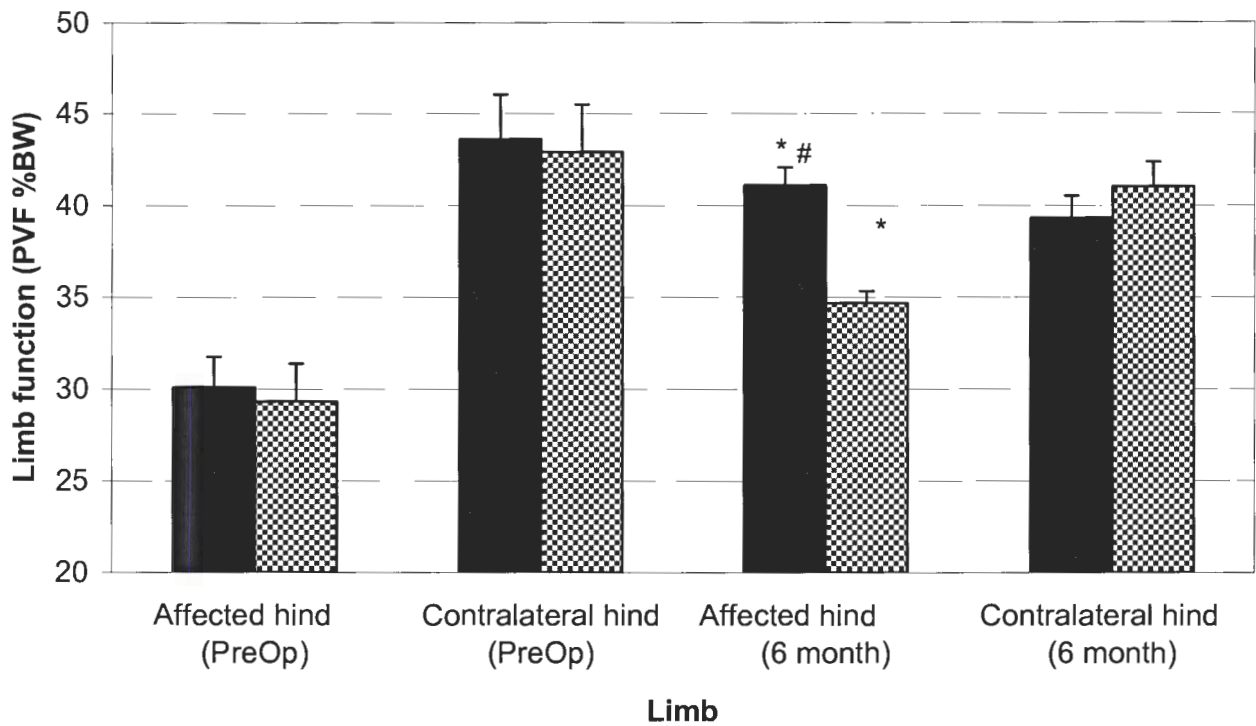


Figure 2. Comparison of peak vertical force (PVF) for dogs in the rehabilitation group (■) and dogs in the exercise-restricted group (▨) preoperatively and at 6 months after surgery. * Significant ($P < 0.05$) difference between time 0 and 6. # Significant ($P < 0.05$) difference between groups.

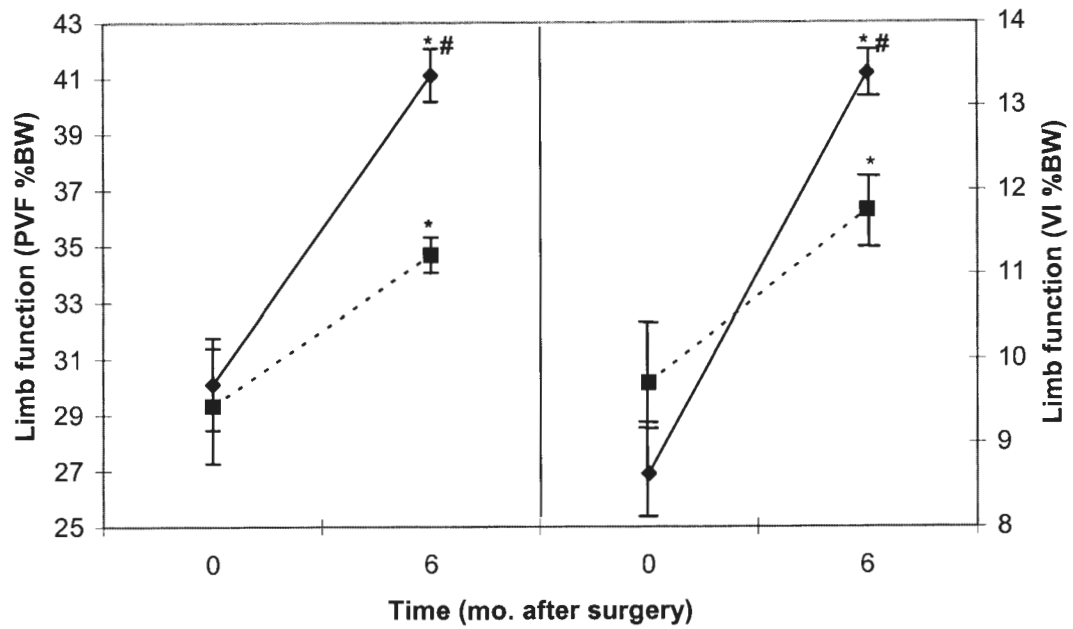


Figure 3. Vertical forces (PVF, VI) before surgery (time 0) and 6 months after surgery (time 6) in the affected limb of dogs in rehabilitation (—) and exercise restricted (-----) groups. * Significant ($P < 0.05$) difference between time 0 and 6. # Significant ($P < 0.05$) difference between groups.

Chapter 3. Kinematic Comparison of Swimming and Terrestrial Motion in Normal Dogs and Dogs Stabilized for Cranial Cruciate Ligament Rupture.

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Introduction

Rupture of the cranial cruciate ligament (RCCL) is a common cause of lameness and is also the most commonly diagnosed stifle injury in dogs.¹ Although surgical management reportedly yields a satisfactory outcome in most dogs, a large number of dogs have residual lameness. Given the frequency of the disease in medium and large breed dogs, traditional postoperative management has not been sufficient.

Although relatively new to veterinary medicine, rehabilitation has been demonstrated to be successful in early and more complete return to function in dogs that have undergone stifle joint surgery. A recent study demonstrated that dogs that underwent postoperative aquatic rehabilitation following surgical stabilization for ruptured cranial cruciate ligament (RCCL) had increases in both peak vertical force (PVF) and vertical impulse (VI) when compared with traditional postoperative exercise restriction². PVF was 18.5% and VI was 13.0% greater in dogs six months following RCCL stabilization and rehabilitation. In fact, PVF and VI were statistically identical to that of the opposite normal limb in dogs that underwent RCCL stabilization and aquatic physical therapy. Despite the promising findings

of this study, joint kinematic data were not collected; this study was limited in its ability to characterize joint range of motion and function.

Kinematic analysis has been used reliably and objectively to characterize motion in a variety of species.^{3,4,5} It has also been used to characterize range of motion in the stifle in normal and CCL deficient canines.^{6,7,8,9} To date, kinematic analysis has not been used to evaluate ROM and limb motion during swimming in dogs. In an effort to characterize limb motion, define ROM, and explain the benefits of aquatic rehabilitation in dogs after surgery for a RCCL, we performed kinematic analysis on the stifle joint of normal dogs and of dogs after cruciate repair surgery while walking and swimming.

In this study, we hypothesized that normal dogs and dogs operated on for RCCL would demonstrate greater hip, stifle, and hock joint ROM, during swimming than walking.

Materials and Methods

Dogs— All adult dogs participating in postoperative rehabilitation at the Iowa State University Veterinary Teaching Hospital (ISU VTH) Canine Rehabilitation Center between June 2000 and October 2001 were considered for inclusion in the study. Selection criteria for the RCCL rehabilitation group included age between 1 and 10 years, body weight between 25 and 45 kg (55 and 100 lb), presence of a RCCL, be enrolled in aquatic rehabilitation at the ISU VTH Canine Rehabilitation Center, be in the three to five week postoperative period for stabilization of RCCL, and be free from additional neurologic and orthopedic diseases. A variety of breeds were represented including Retrievers, Rottweilers, Labradors, and mixed breed dogs. Normal dogs were enrolled from students, faculty, and staff at the ISU VTH. All normal dogs were between 1 and 3 years of age, body weight between 16 and 40 kg (35

and 88 lb), and free of neurological and orthopedic disease. Breeds represented included a variety from the Labrador and Retriever families. Additionally, all dogs were withheld from nonsteroidal anti-inflammatory medications for 7 days prior to enrollment in the study and all owners signed an informed client consent form. Dogs were not randomly assigned, however, they served as their own control for comparison to be made between swimming and walking. The investigators were not blinded to the treatment groups.

Rehabilitation group— Surgical treatment included debridement of the RCCL, partial or complete medial meniscectomy, and an extracapsular stabilization. Postoperative care included administration of an analgesia (0.5 mg/kg [0.23 mg/lb] morphine, IV, q 6 h for 24 hours) and a 2 to 3-day stay in the hospital with short leash walks twice daily. No additional analgesic or anti-inflammatory medications were offered on discharge.

All dogs were discharged from the hospital 2 to 3 days after surgery without a bandage. Owners were instructed to rest the dog at home with activity limited to primarily short (0.5 miles) walks on a leash (for urination and defecation only), twice daily, until suture removal. At 10 to 12 days after surgery, dogs were returned to the ISU VTH for re-examination and suture removal. These re-examination appointments were scheduled on Monday mornings so the dogs could begin rehabilitation at the beginning of the third week after surgery. Rehabilitation was performed twice each day during weeks 3 and 5 after surgery.

All rehabilitation sessions took place at the ISU VTH Canine Rehabilitation Center. Sessions began with 10 minutes of limb massage and placing the limb through a passive range of motion, followed by 10 minutes of walking and 10 to 15 minutes of swimming.

Prior to swimming, each dog was fitted with a personal flotation device^r and walked into the pool^s. Swimming therapy began with alternating intervals of a 1-minute swim followed by 1-minute of rest. This regimen was repeated twice daily (am and pm) so that each dog received at least 10 minutes of swimming daily. Nearly all dogs swam vigorously (limbs continuously moving) from the time they were suspended (no limbs touching the floor or stairs). Aquatic rehabilitation was performed in a pool that is 7'6" feet wide, 14 feet long, and 4 feet deep. Standards set by the National Swimming Pool Foundation of America,¹⁰ required water temperature be maintained between 90° to 92°, total alkalinity at 80 to 120 PPM, total bromine concentration at 3 to 5 PPM, and pH at 7.2 to 7.6. Dogs were housed in stainless steel cages in the rehabilitation facility for the duration of the weeks they were undergoing treatment and were fed their normal diets as instructed by their owners.

Therapeutic walks were performed on a treadmill.^t Dogs were allowed four swimming and walking sessions prior to data collection for acclimation in the pool and on the treadmill.

Normal Group—All dogs belonged to faculty, staff, or students at the ISU VTH, and participation was granted via informed consent. Owners were instructed to allow normal activity in days prior to data collection. Dogs were dropped off to the ISU VTH the morning of data collection, housed in stainless steel cages in the rehabilitation facility, and were taken for a short walk to urinate and defecate prior to swimming and walking. Prior to data collection, a short period of conditioning to treadmill walking was performed until the patient could comfortably walk without distraction.

^r S.E.R.F. Leisure Products Inc., Mississauga, Ontario, Canada

^s Aquaswimjet-Swimpool 14', Rio Plastics, Port of Brownsville, TX

^t ICON Health and Fitness, Inc., Widestride Duo48, Logan, UT, 84321

Data collection—Data were generated from the patient's history, signalment (body weight, breed, age, sex) and physical examination findings (body condition score). Each dog was fitted with retroreflective markers^u placed over the iliac crest, greater trochanter of the femur, femorotibial joint between the lateral femoral epicondyle and the fibular head, and lateral malleolus of the distal portion of the tibia, and the distal lateral aspect of the fifth metatarsal bone to define the hind limb joint angles. Placement of the markers was done by the same researcher (GSM) each time. Three-dimensional (3-D) volumes were calibrated and leveled in the pool and on the treadmill using two 60Hz video cameras^v and a surveyed 3-D calibration object (12 points).^w Dogs were videotaped in the respective calibrated volumes. The dogs were walked at 0.9m/s and at 1.3m/s on a treadmill. Swimming trials were performed in a transparent pool (4 ft wide, 4 ft high, and 8 ft long, made from 3/4inch clear acrylic).

The selected velocity of 0.9 and 1.3 m/s was a walking pace in all dogs. This velocity was selected because many lame dogs that would use the affected limb at a walk would carry the limb at a trot, thereby adding to trial variation. Given the degree of lameness in the dogs in this clinical study, kinematic analysis at a walk was deemed most appropriate.

Data analyses— 3-D spatial positions of these markers were established by digitizing the videotapes using a Peak Performance Motion Analysis System.^x Data were smoothed using a fourth-order, low-pass Butterworth filter with a cut-off frequency of 3 Hz. Two-dimensional coordinates from each camera were used as input to a direct linear transformation algorithm which predicted the three-dimensional coordinates of each marker.

^u 3290 Scotchlite Reflective Sheeting, 3M, St. Paul, MN, 55133

^v WVD-5100 Camera, Panasonic, Secaucus, NJ, 07094

^w Peak Performance Technologies, Englewood, CO, 80112

Maximal extension and flexion angles of the stifle joint were determined for three consecutive cycles of motion from which the joint ROM was computed. Trials were considered invalid if the patient was distracted or uncomfortable, the patient's long axis was not parallel to the long axis of the pool or the treadmill, or if the patient moved either forward or backward more than 3cm during the three consecutive gait cycles collected. A cycle was considered "toe off" of the pelvic limb during stance phase through the complete swing phase and through stance phase up to the point of "toe off". Data for the three cycles were averaged and a mixed model ANOVA (Group \times Exercise) was used to compare maximal flexion and extension, joint ROM, and angular limb velocities between exercise modalities and groups. An alpha level of 0.05 was chosen to specify statistical significance.

Results

Thirteen dogs were included in the normal group and seven dogs were included in the RCCL rehabilitation group. Significant differences were not detected between groups regarding body weight or body condition score. Mean body weight for dogs in the RCCL rehabilitation group was $34.9 \pm 8.3\text{kg}$ ($76.8 \pm 16.3\text{lb}$), compared with $30.0 \pm 7.1\text{kg}$ ($66.0 \pm 15.5\text{lb}$) for dogs in the normal group. Mean body condition score, on a 1 through 9 rating system (with 1 being gaunt and 9 being obese), for dogs in the RCCL rehabilitation group was 6.0 ± 0.64 and for dogs in the normal group was 5.7 ± 0.75 . Additionally, there were no differences in the distribution of sex. Breed differences did exist with all dogs in the normal group being of the Labrador family while RCCL rehabilitation group varied from Rottweilers and Labradors to a few mixed-breed dogs.

^x Peak Performance Technologies, Englewood, CO, 80112

In the hip, swimming produced a greater range of motion than either walking condition in normal dogs. No differences in ROM were noted in operated dogs between any exercise conditions (Figure 1). In the hip, swimming also produced a greater angular velocity than either fast walking or slow walking. Fast walking produced a greater angular limb velocity in the hip when compared with slow walking, and no differences were seen between normal dogs and operated dogs.

In the stifle, swimming produced a greater range of motion than either walking condition. This was seen in both normal and operated dogs, and is primarily due to significantly greater maximal flexion. Range of motion in the stifle was significantly less in operated dogs than normal dogs (Figure 2). In the stifle, normal dogs also had greater angular limb velocities in all conditions than operated dogs.

In the hock, swimming produced significantly greater range of motion than either walking condition. This was due to increased flexion. Normal dogs had significantly greater range of motion than operated dogs did, and both walking conditions were shown to produce a greater extension than swimming conditions (Figure 3). In the hock, swimming produced greater angular velocities than either walking condition and normal dogs had a greater angular velocity than operated dogs for swimming. Fast walking also produced greater angular velocities than walking did, but no differences were noted between normal and operated dogs.

Discussion

When normal dogs swim they produce a greater ROM in the hip, stifle, and hock when compared with either walking condition. Operated dogs also demonstrated a greater ROM in the stifle and hock during swimming when compared to walking.

Additionally, we demonstrated that the additional ROM seen in dogs during swimming is a function of greater flexion. These findings suggest that to maximize ROM after joint surgery, swimming should be part of the rehabilitation protocol. This is particularly important in the stifle.

These findings are important as there is an emerging body of information in humans that support rehabilitation strategies that provide the greatest ROM. Initial research showed that immobilization of limbs was detrimental to tissues.^{11,12} Later research demonstrated the beneficial effects of range of motion in the health of tissues, while not increasing surgical failure rates.¹³⁻¹⁵ In humans, early physical rehabilitation following joint surgery resulted in earlier and more complete return to function, reduced the chances of re-injuring the joint, and did not increase intra-articular graft failure rates.¹⁶⁻¹⁹ In athletes recovering from ACL surgery, it has been reported that physical rehabilitation reduces pain, joint effusion, capsular contraction, and periarticular fibrosis while increasing range of motion, muscle mass, and limb strength.²⁰⁻²³ Additionally, it has been suggested that early postoperative physical rehabilitation reduces the development of arthrofibrosis and osteoarthritis.²⁴⁻²⁵

Without stabilization, osteoarthritis is known to progress in RCCL disease,²⁶ and in humans, range of motion (ROM) and stifle flexion are significantly reduced in patients with osteoarthritis.²⁷ In dogs with chronic RCCL all pelvic limb joint motion was shown to change over time and the stifle flexion was more pronounced throughout stance phase and

early swing phase and failed to extend during late stance phase.²⁸ A recent trial in humans tested stifle ROM and pain scores before and after either terrestrial rehabilitation or aquatic rehabilitation.²⁹ The results indicated that knee ROM in patients with osteoarthritis showed no significant differences between pretest or post-test measurements. These results can not be directly applied to the dog, as limb positions in water vary significantly between dogs and people. However, what can be applied to dogs is the finding that human patients who underwent aquatic exercise had significantly lower pain scores due to the decreased load that joints bear during aquatic exercise. The decreased pain and load bearing may translate to the increased ROM.

In this trial we focused on comparing ROM in terrestrial and aquatic based rehabilitation. We did this to evaluate the benefits of an aquatic program. On land, joint reactive forces can reach several times body weight, which may stress the unstable joint. Osteoarthritis, degeneration of articular cartilage and formation of new bone at joint surface margins, are responses to instability and repeated stresses.^{25, 30, 31} In water, the effects of gravity and axial loading can be substantially diminished³² or be entirely eliminated if the patient floats.³³ Postoperative rehabilitation, that minimizes stresses on these joints and encourages range of motion and muscle activity, should provide a safe functional program.

Angular limb velocity is a measure of the speed at which a joint angle changes. This provides an excellent comparison when limbs and motion are identical, yet when conditions are not identical its relevance is equivocal. In this trial limb length was not homogenous and exercise conditions varied. Angular limb velocity data may not be equivocal as it may highlight the benefits of non-weight bearing activities (swimming) compared with that of weight bearing (walking). During a walk, a greater mass must be put in motion and what is

consistently seen are lower angular limb velocities. Swimming produced greater velocities, and we postulate that is a function the lower mass being moved. Reduced the mass in motion leads to reduced force placed across the joint being moved.

Performing a study evaluating limb function in dogs with naturally occurring RCCL is problematic because of the number of variables, inherent to the conditions, that must be controlled for. In this study, we controlled for freedom from other orthopedic or neurologic diseases, body weight, and postoperative management in the rehabilitation group. We did not control the procedure type performed, the surgeon, the severity of preoperative osteoarthritis in the rehabilitation group, or the home treatment for the normal group. Dogs in this trial were not randomized. They did serve as their own control for comparisons within groups, but not between groups. Although all dogs did complete habituation on the treadmill, none of the patients were habituated to the acrylic pool prior to data collection. Data from dogs that would not swim in the acrylic pool, despite their swimming in the rehabilitation pool, were discarded. Additionally, data were not analyzed if the cameras were moved at all during the taping segment, if the video field was unable to capture the entire swing and stance phase of a gait cycle, or if speeds on the treadmill were not discernable.

Another limiting aspect of this study relates to placement of the retroreflective markers. In this study, these markers were placed in direct contact with the skin. Several studies³⁴⁻³⁶ criticized the ability of skin surface markers to adequately estimate joint centers. Another study⁶ worked to overcome this by using orthopedic implants. This would have been impractical for a study of this type. Additionally, one may argue that the implant itself may contribute more to trial variation by interfering with normal locomotion. In this study,

we accepted the inherent movement over the skin, even though it existed only as a potential confounding factor.

Finally, the data recorded on the treadmill may have added to the error in this study. We performed kinematic analysis with the dogs at a walk on a treadmill. It is possible that kinematic analysis at a trot, a more rigorous gait, would have provided different results. Additionally, variation between treadmill and overground walking has been shown to exist in humans.³⁷ We performed gait analysis at a walk because many dogs that would use the limb at a walk would be non-weight-bearing at a trot and the treadmill served to maximize our data collection.

Rehabilitation in dogs following joint surgery has become an integral part of postoperative care. It may be that the preservation of ROM allows rehabilitation to be more effective at returning dogs to full function when compared with home rest and immobilization. The data generated from this trial have served to characterize the ROM in normal dogs and dogs following surgery and rehabilitation for a RCCL. It is important to note that if ROM is a factor in rate of return to function in animals, then aquatic rehabilitation provides the best opportunity for a full recovery by maximizing ROM. In this trial we found that stifle and hock ROM and maximal flexion were greatest with swimming. Hip ROM, however, was minimally affected by the various exercise conditions. Knowing this, we recommend that aquatic rehabilitation should be performed following stifle and hock surgery in an effort to maximize ROM and preserve maximal flexion.

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Figure 1. Comparison of range of motion in the hip of normal dogs and dogs operated for ruptured cranial cruciate ligaments (CCL) while swimming and walking at both 0.9m/s and 1.3m/s.

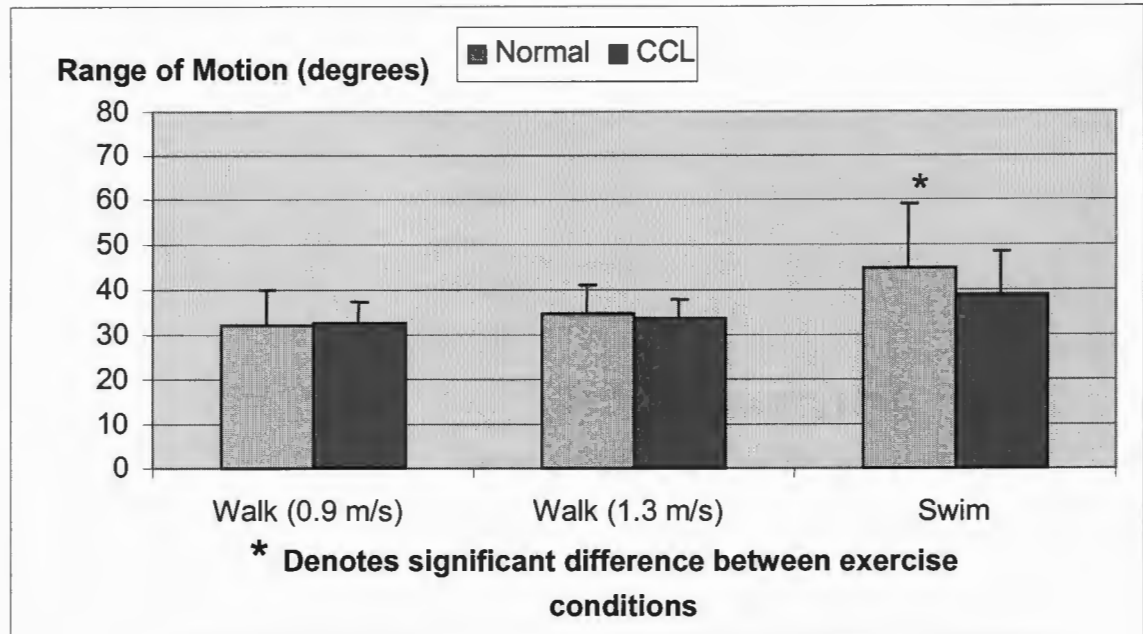


Figure 2. Comparison of range of motion in the stifle of normal dogs and dogs operated for ruptured cranial cruciate ligaments (CCL) while swimming and walking at both 0.9m/s and 1.3m/s.

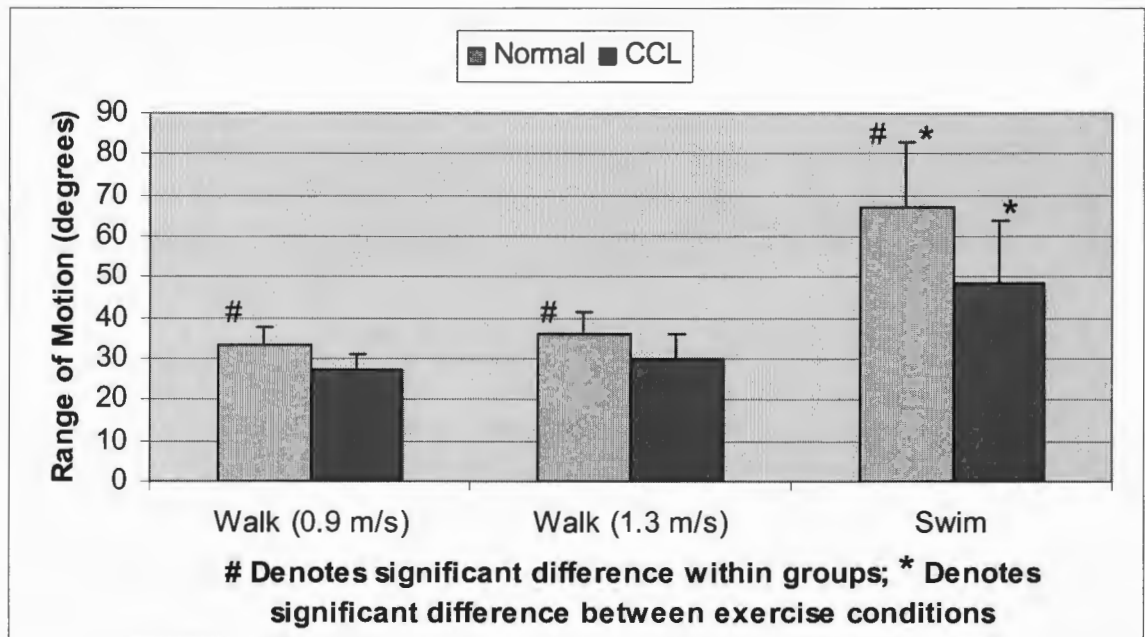


Figure 3. Comparison of range of motion in the hock of normal dogs and dogs operated for ruptured cranial cruciate ligaments (CCL) while swimming and walking at both 0.9m/s and 1.3m/s.

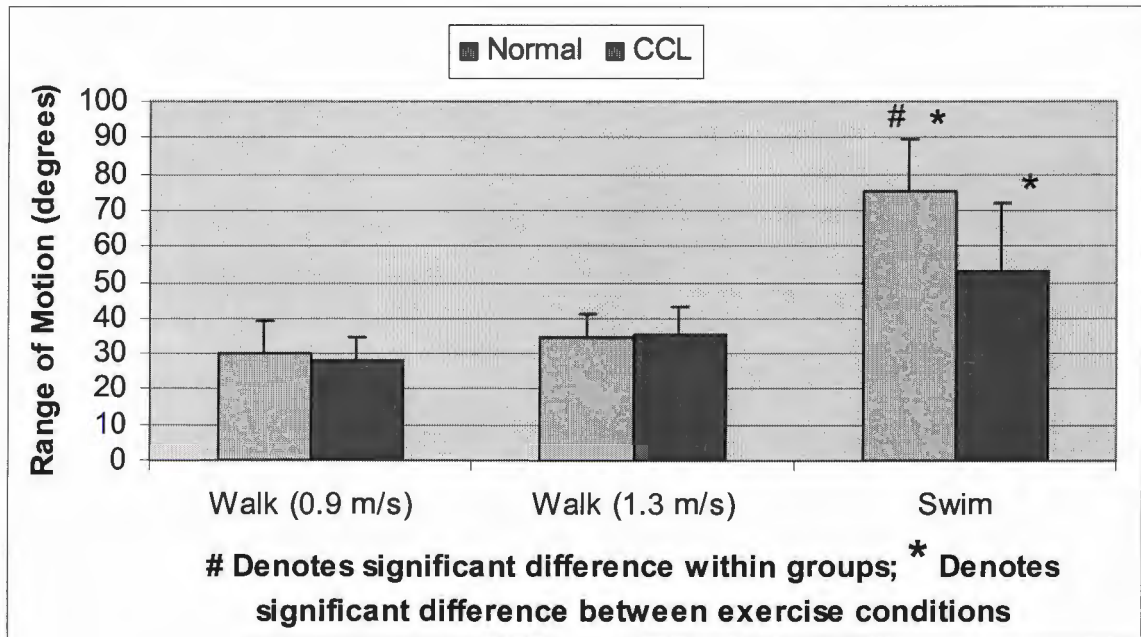


Table 1. Angular limb velocity data comparison of the hip, stifle, and hock during swimming and walking at 0.9m/s and 1.3m/s.

	Swimming	Walk (0.9m/s)	Walk (1.3m/s)
Hip			
Normal (N=13)	160.9 (1)	62.79 (2)	88.15 (3)
CCL Operated (N=7)	122.74 (1)	68.71 (2)	87.38 (3)
# denotes significant difference within groups			
Stifle			
Normal (N=13)	151.53 (1)	154 (1)	182.26 (1)
CCL Operated (N=7)	94.09 (2)	105.03 (2)	138.9 (2)
# denotes significant difference within groups			
Hock			
Normal (N=13)	216.91 (1)	55.75 (3)	80.9 (4)
CCL Operated (N=7)	134.15 (2)	48.61 (3)	70.53 (4)
# denotes significant difference within groups			

Chapter 4. Conclusions

Canine rehabilitation is currently in a developmental phase, and much work needs to be done to maximize the benefits of postoperative care in our veterinary patients. This preliminary work will hopefully stimulate other research groups to focus to this novel area in veterinary medicine.

This manuscript has demonstrated the value of rehabilitation following joint surgery in dogs; however it is only the beginning of what needs to be done. We have used this to document reasonably safe starting point. The protocols advocated in this text were based on our three years of clinical experience performing aquatic rehabilitation on dogs. We have learned much and the protocols have changed drastically over the years. We expect these protocols to continue to evolve as additional research in this area is completed.

Future research needs to evaluate different exercise protocols, to determine the value of inpatient and outpatient therapy, and test the effects of rehabilitation on other orthopedic and neurological diseases. Additionally, future studies should combine force platform gait analysis and kinematic comparison to evaluate changes in range of motion and the effects with ground reaction forces. Finally, non-traditional methods of rehabilitation, like electrophysiological muscle stimulation and acupuncture should be tested and their effects on the outcome of orthopedic and neurological diseases be determined.

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